OSCILLOGRAPHS.

The phenomena connected with the behaviour of alternating currents present a wide field for experimental inquiry which has, up to the present, been but imperfectly explored. The investigation of the wave-forms of alternating potential differences and currents under various conditions of their actual use is a matter, not only of great theoretical and scientific interest, but also of the highest practical importance, since the shape of the wave-form under given conditions, and the alteration of shape produced by any alteration of conditions, are factors which largely affect the efficiency and economy of working. As examples showing the increased efficiency that may be obtained by choosing a suitable wave-form, we may quote the results obtained by Messrs. Rössler and Wedding, and by Messrs. Barr, Beeton and Taylor. The former experimenters showed,[1] in an investigation on the luminous efficiency of the alternate current arc, that the light per watt when using an alternator giving a flat-topped E.M.F. curve was 44 per cent. higher than when using a machine that gave a peaked curve. Messrs. Barr, Beeton and Taylor, in a research on the efficiency of transformers, found,[2] on the contrary, that a peaked wave-form was the most suitable one to employ. The reactions that take place between alternators running in parallel is another case in which the wave-form is of very great practical importance.

It will be readily understood, therefore, that it is most desirable that we should have some simple method of observing and studying the wave-form of an alternating current or potential difference. Such a method is supplied by the instruments known as oscillographs. Before the invention of these instruments the only means of studying wave-forms was by the exceedingly laborious "point-to-point" method. Suppose that there is a circuit through which is flowing an electric current which is varying periodically at the rate of, say, n, complete cycles per second, and that it is desired to obtain the wave-form of this current. At any particular instant the current will have a certain definite magnitude and direction, and $1/n$th of a second later the current will again have the same magnitude and direction. If, by means of an automatic contact-maker, a galvanometer is brought into circuit at intervals of $1/n$th of a second, there will be given to the galvanometer needle a succession of impulses due, in each case, to the same current, and consequently a steady deflection of the needle will be produced from which the particular instantaneous value of the current can be determined. To obtain, however, the complete wave-form, we must determine the value of the instantaneous current at *every moment* during the cycle, or at a sufficient number of moments to enable a smooth curve to be drawn. Having found one point on the wave-form in the way described, the contact-maker is shifted so as to bring the galvanometer periodically into circuit at some other moment in the cycle, and a second point on the curve is then found. Again the contact-maker is shifted and a third point is obtained, and thus, point by point, the whole curve may be built up.

This method is open to two objections. In the first place, it is only applicable to cases in which the wave-form is undoubtedly steady, all transient effects being obviously unobservable by such a process, and, secondly, it is so lengthy that elaborate researches are practically precluded. As much as four or five hours may, indeed, be spent in obtaining a single curve, and then, even after all this labour, it is more than possible that the conditions will be found to have altered during the experiment, and the curve, in consequence, to be useless. By means of the oscillograph and kindred instruments, however, experiments can now be carried out in a few minutes which occupied days by the old "point-to-point" method, and not only can steady wave-forms be examined, but the most fleeting effects can be studied with equal ease.

An oscillograph may be defined as a galvanometer the deflection of which, at any instant, is practically proportional to the current flowing through it at that instant, in spite of the current varying very rapidly in strength or in direction. For this to be possible it is necessary for the free periodic time of the moving part of the instrument to be very short, less, generally, than 1/30th, of the periodic time of the effect to be observed. The instrument must also be perfectly dead-beat, the moving part taking up instantaneously the deflection proper to the current flowing through the instrument, for if there be any tendency to overshoot the mark it will cause the observed wave-form to be distorted from its true shape. In addition to this, since one is dealing with rapidly varying currents, it is necessary for the self-induction of the instrument to be practically nil, and for all effects due to hysteresis or eddy-currents to be eliminated. The original idea of the oscillograph is due to M. Blondel, who pointed out, in 1893, the principles on which such an instrument should be designed, and all the oscillographs since produced owe their inspiration to M. Blondel's work.

Two other instruments have been invented and developed by which the same end might be attained, namely, the observation or recording of rapidly varying currents or potential differences. These are the Abraham-Carpentier rheograph and the Hess-Braun oscillo-radiograph. With these instruments, since they are not, strictly speaking, oscillographs, we do not propose to deal in detail, but must content ourselves by giving a brief account of the principles on which they are constructed. In the rheograph, instead of making the free periodic time of the instrument excessively small, M. Abraham uses a galvanometer with a period of about 1/10th of a second, and attempts to compensate errors due to the inertia of the moving part by utilising the effects of electromagnetic induction. With this instrument M. Abraham, it is said, has been able to study oscillating discharges having a period of about 1/10,000th of a second; but the adjustment is not an easy matter, and, moreover, has to be made every time the instrument is used. In the Hess-Braun oscillo-radiograph the difficulty of

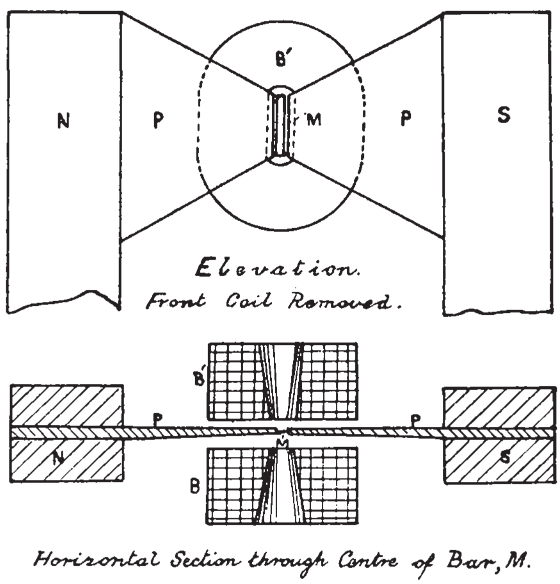

Fig. 1.—M. Blondel's oscillograph.

sufficiently reducing the inertia of the moving part is overcome in a very ingenious manner by using, as the galvanometer "needle," a beam of kathode rays in a vacuum tube. This beam is arranged to produce a bright spot on a fluorescent screen, and the movements of this spot are observed when the beam is deflected by the varying currents passing through two bobbins of wire on either side of the vacuum tube. Unfortunately these bobbins, possessing self-induction, introduce errors. Another difficulty in this apparatus is to obtain good definition, and also sufficient intensity of illumination. On account of the small intensity it is only possible to use this instrument for the study of cyclic phenomena where, as the spot of light can be caused to travel over the same curve again and again, the curve can be observed or photographed.

Neither of these instruments has been brought to the same degree of perfection as the oscillograph, which has been developed into a very perfect instrument by M. Blondel in France and by Mr. Duddell in England. M. Blondel originally suggested three systems on which oscillographs might be constructed, in which the moving part consisted respectively of a small bar of soft iron, a vibrating plate of iron, and a light coil on a bifilar suspension. The instrument which M. Blondel first perfected, and with which his well known researches on the alternate current arc were carried out, was constructed on the first of these systems. The diagram (Fig. 1) shows the chief principles of its construc-

[1] *The Electrician*, 1894, vol. xxxiii.
[2] *Journal* of the Institution of Electrical Engineers, 1896, vol. xxv.

tion. A small bar of soft iron, M, to which is attached a light mirror, is pivoted between the pole-pieces, P.P., of a powerful magnet or electro-magnet. These pole-pieces are laminated and are specially shaped to give as strong a magnetic field in the air gap as possible. On each side of the pole-pieces is a coil of wire, B.B., through which the current to be observed flows. This current produces a field at right angles to that of the field magnet, and so deflects the iron bar through an angle which, if small, is proportional to the current. M. Blondel has produced an instrument of this type having a free periodic time of 1/6000th of a second; and, by replacing the small bar with an iron band stretched between the pole pieces, he has constructed an instrument having much smaller free periodic time than any other type of oscillograph—indeed as small as 1/50,000th of a second—but the sensibility at this high frequency is not very great. At a frequency of about 10,000 vibrations per second, its sensibility is about the same as that of the other types of instrument.

The credit of developing the bifilar oscillograph is due to Mr. Duddell, who, as the result of a long series of investigations

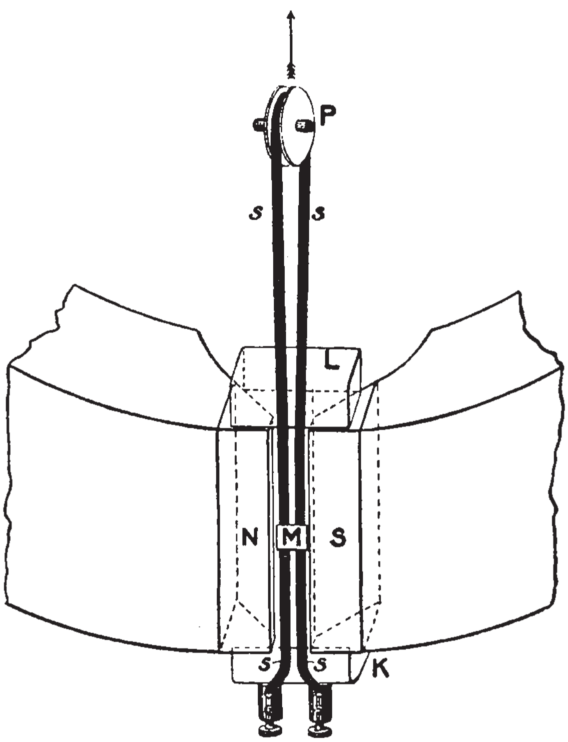

FIG. 2.—Mr. Duddell's oscillograph. (From the *Journal* of the Inst. Elect. Eng., vol. xxviii., 1899, p. 8.)

carried out at the Central Technical College, has produced instruments of this type possessing a high degree of perfection, and by means of their use has brought to light a number of new experimental facts. The principle of Mr. Duddell's oscillograph will be easily understood by reference to Fig. 2. The current to be observed flows up one side and down the other of the continuous strip of phosphor-bronze, *s.s.s.s.* This strip is looped over the pulley, P, which is attached to a small spring balance (see Fig. 3) by means of which the tension on the strip can be regulated. Each arm of the loop passes through the gap between the poles, N.S., of a powerful electro-magnet. The loop carries at its centre a mirror, M, which is made of a small piece of silvered cover-glass cemented to the strips. When a current passes through the loop, one side is moved forward and the other backward, and the mirror is thus deflected through an angle proportional to the current. The phosphor-bronze strips are held in position at the bottom by being clamped between ebonite insulating pieces at K, and at the top by being drawn against the single ebonite piece at L. It will be observed, therefore, that the only part of the strip that takes part in the vibration is that between K and L, and not, as might otherwise be supposed, the whole length from K to the pulley P.

By the use of phosphor-bronze, Mr. Duddell has found it possible to make very light strips having sufficient strength to enable considerable tension to be used, and having, at the same time, good conductivity. He has been able to bring down the free periodic time to 1/10,000th of a second, and, with a free periodic time as low as this, the mirror can easily follow, with extreme accuracy, the vibrations of an electric current alternating at the rate of 300 complete cycles per second, while even if the alternating current has a periodic time as short as 0·001 second, or even less, the record may possess sufficient accuracy for many purposes. The narrow gap through which the strips pass is only just large enough to allow of their free movement, and as the break in the magnetic circuit is consequently very small, the field can be made very intense. This space is filled with damping-oil, which is retained in it by a lens forming a front to the gap, and thus the strips are confined in a narrow oil-bath, in which they have only just room to move, the damping in consequence being very efficient and rendering the instrument accurately dead-beat.

Already the Cambridge Scientific Instrument Co. have constructed many specimens of two types of this form of oscillograph,

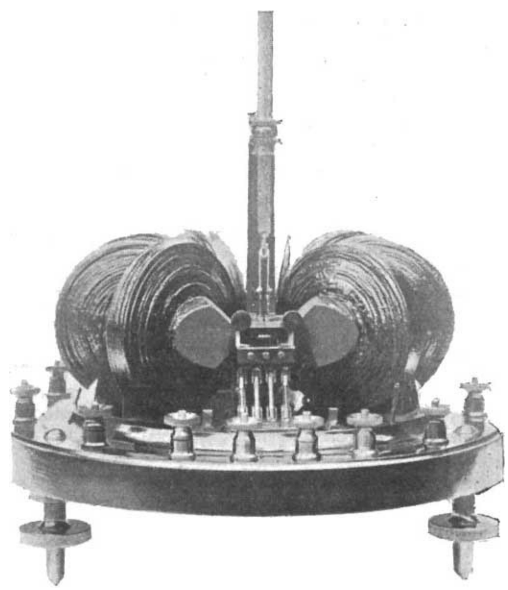

FIG. 3.—Mr. Duddell's oscillograph. High frequency pattern.

a large one for projection work and a high frequency instrument for more accurate research work. The general design in both types is the same, the chief difference lying in the high frequency pattern having its moving parts smaller and lighter, by which means the periodic time of 1/10,000th second has been obtained, whereas the free periodic time of the projection instrument is 1/2000th of a second. The instrument is made with two loops fixed side by side in the gap so that one may be used to give the wave-form of the current while the other is used to give the wave-form of the potential difference, the two curves being thus obtained simultaneously. There is a third fixed mirror between the two vibrating mirrors which is used to give a zero line. Small tangent screws enable the positions of the moving mirrors to be adjusted to zero. From Fig. 3, which is a photograph of the double instrument, a good idea of its general appearance and construction may be obtained. The light band between the poles of the magnet shows the position of the mirrors, but the illustration is on too small a scale for the mirrors themselves to be distinctly visible. This is not surprising when one considers that their actual size is only 1·0 mm. high by 0·3 mm. wide by about 0·1 mm. thick. The strips are connected through the four small upright fuses with the terminals on the front of the base of the instrument. The normal working current in the strips is 0·10 amp., and the sensibility at a scale distance

of 1000 mm. is nearly 600 mm. per ampere. The other terminals which are seen make connection with the magnet, on which there are four pairs of coils the ends of which are brought out to separate terminals so that the coils may be connected up

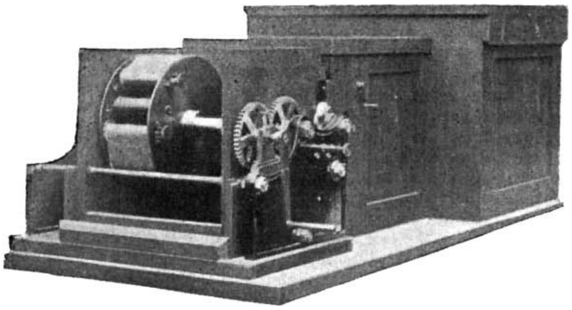

FIG. 4.—Photographic recording arrangement.

in series or parallel to suit the voltage obtainable. The magnet is wound so that the coils may be connected in series direct across 100 volt mains.

It is interesting to note that the oscillograph may be used to show the power curves, as well as the curves of current and potential difference. For this purpose it is only necessary to excite the electro-magnet by the alternating current, instead of from a direct current supply, when the instrument will act as a watt-meter, and give the power-curves. The accuracy is not so high when the oscillograph is used in this way; but the possibility of so using it is very advantageous, both for purposes of demonstration and research.

In order to observe the actual shape of the wave-form, it is necessary to introduce a movement of the beam of light reflected from the oscillograph mirror at right angles to the direction of vibration it already possesses. This may be done by observing the movements of the spot of light in a rotating mirror, or, if permanent records are desired, by receiving the spot on a moving photographic plate or film. This method may be used for observing or

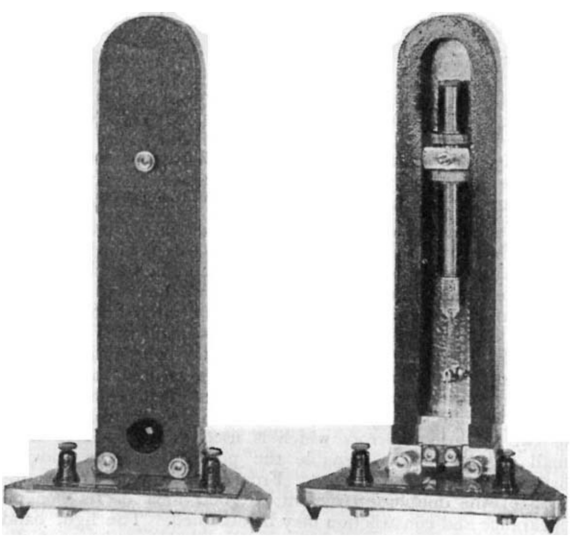

FIG. 6.—Mr. Duddell's portable pattern oscillograph.

recording any variations in current, whether they be periodic or not. In Fig. 4 is shown a photograph of the recording arrangement. The oscillograph is in the back part of the box, and in the front part may be seen the recording drum, which carries Kodak daylight changing spools. There is a shutter between the oscillograph and the film which enables any length of film up to 40 cm. to be used at each experiment, and this shutter carries a contact maker which can be used to start any non-periodic phenomena it may be desired to record. For the cases in which it is only periodic changes which have to be studied, Mr. Duddell has devised a very convenient arrangement in which the rotating mirror is replaced by one which is vibrated in synchronism with the waves of potential difference or current under observation. The mirror is vibrated by a small synchronous motor, and the spot of light is reflected from it on to a transparent screen above it; as the mirror moves with a uniformly increasing displacement the wave form is drawn on this screen, and when arrived at the full extent of its motion, the mirror is pressed back suddenly to its initial position, the beam of light being interrupted during this return journey by a shutter attached to the motor shaft. The mirror then starts on a fresh swing, and draws a second wave-form on the top of the first, the successive curves appearing, by persistence of vision, on the screen as a single bright line, which may be either traced, or photographed on sensitive paper. The size of the curves is about 3 cm. amplitude on each side of the zero and about 8 cm. in length, one and a half complete wave-forms being shown in this length. Fig 5 shows the synchronous motor in conjunction with the large oscillograph, the photograph illustrating the complete apparatus for projecting the curves on to a wall screen. On the right is the source of light, and the oscillograph is on the extreme

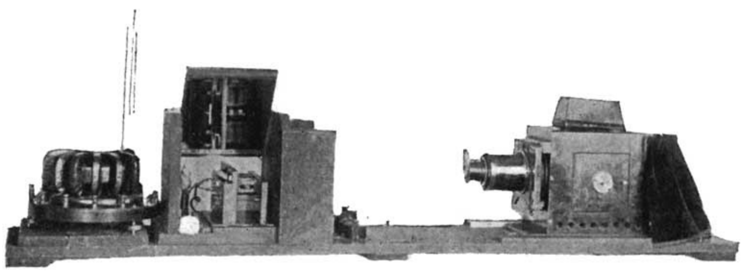

FIG. 5.—Arrangement of apparatus for projection work.

left; to the right of the oscillograph is the motor which drives the synchronous mirror, a view of the top of which is seen reflected in the glass above, this additional mirror being simply introduced to reflect the beam of light, which comes vertically from the synchronous mirror on the motor, horizontally on to the wall. The apparatus will give wave-forms having an amplitude of 50 cm. on either side of the zero and about 150 cm. long, showing in this length one and a half wave-lengths, and sufficiently bright to be seen by over two hundred people at one time.

Mr. Duddell has, we understand, just completed a portable form of oscillograph in which the electro-magnet is replaced by a permanent magnet. This instrument has only one loop of strip, so that it will only show one curve at a time; the free periodic time is 1/5000 of a second, and the sensibility at 1000 mm. scale distance is 750 mm. per ampere. Fig. 6 is a photograph of this small oscillograph, and shows the instrument with and without the front which protects all the working parts. The whole apparatus for observing wave-forms—oscillograph, source of light and rotating mirror—is fitted up ready for use in a small and easily portable box, and should prove of great value to central station engineers and others who employ alternating currents.

In Fig. 7 are shown some examples of curves of current and potential difference obtained by means of the oscillograph. These curves were photographed on to a falling plate, and are here reproduced half full size. Curve 1 shows the wave-forms of the P.D. between the terminals of a dynamo sending a current through an inductive and non-inductive resistance in series, and of the P.D. between the terminals of the non-inductive part, as well as the wave-form of the current flowing in the circuit. It will be seen that the self-induction has caused the current curve to be out of phase with the dynamo P.D., but there is no distortion of the shape. Curve 2 shows the characteristic wave-forms of the current and P.D. of an alternating current arc, burning between solid carbons. The P.D. has a high peak at the beginning, and the current curve lies flat along the zero line at the beginning and end of each half-wave. Curve 3 is for an arc burning between carbon

and zinc; these waves are particularly interesting, as it would be practically impossible to obtain them by the "point-to-point" method, since arcs between carbon and metals burn very unsteadily. The arc, it will be seen, only burns for half a period; when the metal is positive (upper curves) the current is able to flow, and the P.D. and current curves have the shape characteristic of the same curves for the carbon arc, only somewhat accentuated; for the other half period, when the metal is negative no current flows at all, and the current curve is flat along the zero line, the P.D. curve being, in consequence, that given by the dynamo on open circuit. The three curves are for a frequency of 100 periods per second. Curve 4 shows the P.D. and current through the primary of an induction coil in which the contact-maker was driven by a motor, no condenser being used. The steady growth of the current and its rapid fall at break can be clearly observed in the current curve. From the P.D. curve it will be seen that the P.D. at the start is high, since, until the current begins to flow, the P.D. between

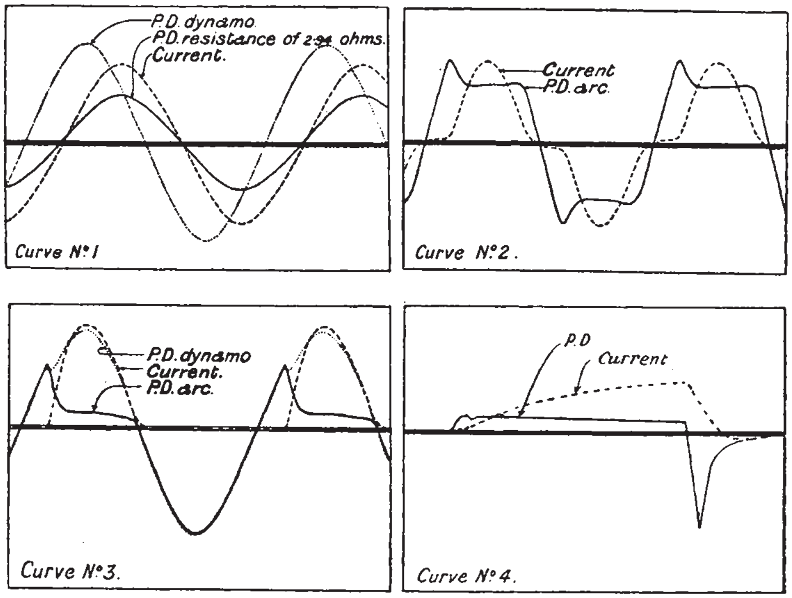

FIG. 7.

Data for Curves in Fig. 7.

No. of Curve.	Wave Forms for.	Periods per second.	Scale of P.D. Curve.	Scale of Current Curve.
1	Non-inductive Resistance.	100	1 mm. = 10 volts.	1 mm. = 2 amps.
2	Solid Carbon Arc.	100	1 mm. = 6 volts.	1 mm. = 2 amps.
3	Zinc-Carbon Arc.	100	1 mm. = 10 volts.	1 mm. = 2 amps.
4	Primary of an Induction Coil.	60 breaks	1 mm. = 2 volts.	1 mm. = 1 amp.

the terminals of the coil is equal to the E.M.F. of the cells. As the current rises, the P.D. between the terminals of the coil falls, due to the drop in volts in the circuit outside the coil; finally the break occurs and there is a large kick of the P.D. in the opposite direction to that applied.

From what has been said some idea will be gathered of the great value of the instrument that has been put into our hands by the invention of the oscillograph. To the scientific investigator it opens wide fields for experimental research, and it will enable the engineer to know more about the currents and E.M.F.'s with which he works. In addition, the projection oscillograph should prove invaluable for lecture and demonstration purposes, for even the simplest problems of alternate current working are by no means easy of comprehension by the average electrical student, who approaches them with only a bowing acquaintance with differential calculus and Fourier's theorem. The remarkable clearness with which their working can be demonstrated on the screen by the oscillograph will go a long way to give students a clear idea of their properties.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

OXFORD.—Mr. T. Loveday, of Magdalen College, has been elected John Locke Scholar for the ensuing year.

Mr. G. C. Bourne has been re appointed a delegate for the extension of University teaching.

The electors to the Wykeham Professorship of Physics have appointed Mr. J. S. Townsend, Fellow of Trinity College, Cambridge, and Demonstrator in the Cavendish Laboratory.

CAMBRIDGE.—The Clerk Maxwell Scholarship in physics is vacant through the election of Mr. J. S. Townsend to a professorship at Oxford. Candidates are to apply to Prof. J. J. Thomson by December 18.

The British Westinghouse Electric Company have presented to the Engineering Laboratory a valuable dynamo and other apparatus illustrating the generation and use of polyphase currents.

AN opportunity for seeing the Northampton Institute, Clerkenwell, and examining some of the work done in the laboratories, will be afforded to-morrow evening (December 7), when the annual prize distribution and members' and students' conversazione will be held. Sir John A. Cockburn, K.C.M.G., will distribute the prizes.

IN an important article by Dr. William Wallace in the current number of the *Fortnightly Review*, on "the Scottish University crisis," attention is drawn to the urgent need there is for a greatly increased expenditure upon Scottish universities if they are to maintain the reputation they have enjoyed in times gone by. It is urged that a lump sum of not less than 1,500,000*l.* is required to place all the Scottish universities in such a position that their degrees should be regarded as of equal value with those of England, Germany, or even America. Such money is regarded as imperatively necessary for the following main purposes: (1) The conversion of the present skeleton faculties into real teaching organisations; (2) For laboratory and other scientific equipment; (3) For libraries; (4) For the endowment of industrial universities or of genuine industrial faculties in the universities; (5) For the endowment of poor undergraduates; (6) For the endowment of post-graduate research.

DR. OLIVER LODGE made some novel suggestions as to the time, place and purpose of University examinations, in his address to the students of the University of Birmingham on November 28. His proposals amount essentially to this—that examinations should not immediately follow teaching, and that a vacation interval should intervene for private study and revision, quiet thought, assimilation and digestion. Students should not be taken straight from a lecture-room into an examination room, so that they might tell the examiner what the professor had said before they had time to forget it. So he wished to urge that a long vacation should be left between instruction and examination; that the examinations be held in September instead of at the end of June. If no interval for rumination was afforded during student days, if the unrooted ideas were pulled up for inspection by the examiner at the end of each session, and the student turned loose in the holidays empty, swept and only partially garnished, for a period of complete idleness before another filling-in process began, then the last state of that man was liable to be little better than the first. The principle underlying Dr. Lodge's proposals is sound enough, but there are difficulties and objections in the application. What, for instance, is to prevent the student who wishes to obtain a good place in the examination at the commencement of the session